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Results from LEP 1

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Abstract : The large electron positron collider, LEP, at CERN is running since 1989 and its purpose was to study the properties of Z particle during the first phase called LEP 1. Some of the results from LEP 1 are described in this article

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1. Introduction

End of LEP's Z^0 era :

A chapter of LEP, Large Electron Positron collider at CERN, Geneva, got closed during the first week of October 1995. This was the first phase of LEP, called LEP 1, and its purpose was to study the properties of Z particle and related electroweak parameters with $\simeq$ 45 GeV e^- beam colliding with $\simeq$ 45 GeV e^+ beam yielding centre of mass energy of collision of $\sqrt{s} \simeq 90$ GeV. The Z era has been a great success from physics achievements point of view as well for CERN as a major centre for particle physics. In the second phase of LEP, called LEP 2, from 1996 to 2000 the centre of mass energy is gradually upgraded to cross the W pair production threshold by incorporating superconducting RF accelerating cavities in several stages. During 1996 the data has already been taken at LEP 2 with centre of mass energies as 161 and 172 GeV.

First beam in the LEP ring was seen on July 14, 1989, with a short pilot physics run during mid August 1989 when Z events from e^+e^- interactions were recorded by the four LEP detectors : ALEPH, DELPHI, L3 and OPAL. First physics run took place during September 20 to October 10, 1989. Each of the four LEP experiments recorded $\simeq$ 30000 Z events which led to the determination of mass and total width of Z as : $M_z = 91.161 \pm 0.031$ GeV and $\Gamma_z = 2.534 \pm 0.027$ Ge V [1].

LEP detectors :

As mentioned earlier there are four detectors at LEP and these detectors have 4π geometry and the general concept is very similar. For the momentum measurement of charged particles there is a magnetic field (0.5 to 1.5 T) parallel to the colliding beam direction. Basic components of these detectors are summarised briefly in the order of increasing distance from the interaction point : (i) Vertex detector : silicon microvertex detector with a fine spatial resolution of ~10–20 μm. (ii) A multiwire drift chamber to track charged particles with momentum resolution of $\simeq$ 5–10%. (iii) An electromagnetic calorimeter to detect e^-, e^+ and photons. The energy resolution at 45 GeV varies between 1–3%. (iv) A hadron calorimeter to detect energies deposited by hadrons (π, K, p, ...) through total absorption. The typical energy resolution for a total energy of 90 GeV is $\simeq$ 10%. (v) Series of wire chambers outside the hadron calorimeter to detect muons with momentum resolution for a 45 GeV muon as 2–6%. (vi) For the measurement of luminosity there are electromagnetic calorimeters placed on either side of the interaction point and very close to the beam pipe to detect small angle Bhabha scattering ($e^+e^- \to e^+e^-$).

Standard Model :

The understanding of the mechanism responsible for the electroweak symmetry breaking leading to massive W and Z gauge bosons is one of the central problem in particle physics. The simplest mechanism for this is realised in the Standard Model which contains a single complex Higgs doublet with one physical neutral scalar Higgs particle. The four vector bosons describing the electroweak interactions are : γ, Z^0, W^+ and W^-. The mixing of γ and Z is described by electroweak mixing angle $\sin^2\theta_W$. The Standard Model assumes three fermion farmilies/generation (6 quarks and 6 leptons).

Indian participation in LEP :

The Experimental High Energy Physics group of TIFR joined the LEP-L3 collaboration in early 1983. The group members took active part in the following activities. (i) Hardware contribution : 1100 brass tube proportional chambers for the hadron calorimeter were fabricated in the laboratory. Precision stainless steel housings for the chambers were fabricated at BARC central workshop. For the L3 upgrade the group fabricated 7500 wire fixation blocks and assembled 3000 readout PCB's for forward/backward muon chambers. (ii) Group members are taking part in data taking and monitoring of detector. (iii) For the software development group members contributed towards reconstruction, simulation, database packages. (iv) For the physics analysis group members are carrying out extraction of electroweak parameters, QCD, heavy flavour physics and search for Higgs and SUSY particles.

2. What do we observe in e^+e^- interactions ?

Interactions of e^+e^- lead to a pair of fermions in the final state. Lowest order diagrams, see Figure 1(a), are due to γ and Z exchanges plus their interference terms. The t-channel diagrams valid only for e^+e^- in the final state are not shown. The contribution of γ exchange at $\sqrt{s} \simeq M_Z$ is negligible. Examples of diagrams due to virtual and real photons are shown in Figure 1(b) and examples of weak corrections due to fermion loop, box and vertex are

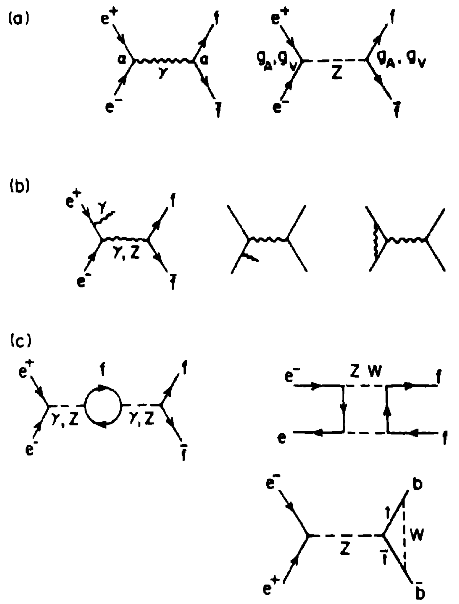

Figure 1. Lowest order diagrams : (a) due to γ and Z exchanges, (b) virtual and real photons, and (c) weak corrections due to loop, box and vertex.

shown in Figure 1(c). It is important to mention that (i) the weak radiative correction is proportional to M_{top}^2, where M_{top} is the mass of the top quark, (ii) radiative corrections result in the modification of experimental quantities like total and partial widths of Z, asymmetries, τ-polarization, electroweak mixing angle *etc.* In order to make experimental measurements independent of theoretical weak radiative corrections we measure all quantities dressed with electroweak effects.

Z decay modes :

Various decay channels of Z into fermion anti-fermion pairs are summarised in Table 1.

Table 1. Z decay modes.

(a) $Z \to$ leptons		
Decay channel	Observed particles	Branching fraction
e^+e^-	e^+e^-	$\simeq 3.3\%$
$\mu^+\mu^-$	$\mu^+\mu^-$	$\simeq 3.3\%$
$\tau^+\tau^-$	low multiplicity final state	$\simeq 3.3\%$
$\nu_e \bar{\nu}_e$, $\nu_\mu \bar{\nu}_\mu$, $\nu_\tau \bar{\nu}_\tau$	none	$\simeq 20\%$
(b) $Z \to$ hadrons		
$u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, $b\bar{b}$	2, 3, 4 high multiplicity jets of hadrons	$\simeq 70\%$

3. What do we measure in e^+e^- interactions ?

Some of the experimental measurements are summarised below :

(a) σ *vs* $\sqrt{s}$:

Experimentally one measures cross sections (σ) as a function of the collision energy for the following final states : $e^+e^- \to$ hadrons, $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-$. Typical energy scan is carried out between 88–94 GeV around the Z-mass. This is termed as the Line shape measurement of the Z peak.

The basic physical parameters that describe the cross section are the mass of the Z, M_Z, its total width Γ_Z and the partial widths Γ_f for decay into fermion pairs. From the lineshape measurements one measures three quantities : (i) position of the peak which defines M_Z, (ii) height of the peak which is proportional to $\Gamma_e.\Gamma_f$ and (iii) width of the distribution which gives the total width Γ_Z.

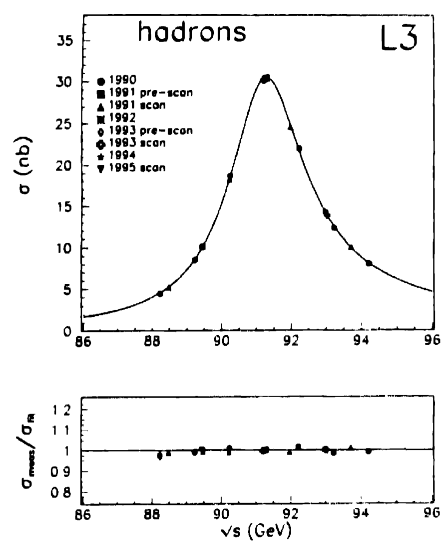

Figure 2. Cross section for $e^+e^- \to$ hadrons as a function of collision energy, fit to the data is shown as solid curve Quality of fit can be seen from the bottom plot

Figure 2 shows the L3 data for the variation of cross section as a function of collision energy and fits to the data are shown as curves.

(b) *Forward-backward asymmetry* :

The forward-backward asymmetry A_{FB} of the final state fermion arises due to vector and axial-vector nature of the Z coupling and it is given by : $A_{FB} = \dfrac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$, where σ_F (or σ_B) is the forward (or backward) cross section when the fermion is in the forward direction (or backward) direction with respect to the initial e^- beam direction. The measurement of A_{FB} leads to the determination of the electroweak mixing angle as can be seen from the following simplified expression evaluated at $\sqrt{s} = M_Z$:

$$A_{FB} = \frac{3(1-4\sin^2\theta_W)}{1+(1-4\sin^2\theta_W)^2} \frac{\left(1-4|Q_f|\sin^2\theta_W\right)}{1+\left(1-4|Q_f|\sin^2\theta_W\right)^2}, \tag{1}$$

where Q_f is the charge of the fermion under consideration.

The following asymmetries are measured at LEP : (i) lepton asymmetries : $e^+ + e^- \to e^+ + e^-, \mu^+ + \mu^-, \tau^+ + \tau^-$, (ii) $b\bar{b}$ asymmetry : $e^+ + e^- \to b + \bar{b}$, (iii) $c\bar{c}$ asymmetry : $e^+ + e^- \to c + \bar{c}$ and (iv) quark charge asymmetry ($< Q_{FB} >$).

(c) τ Polarization :

τ leptons from decay of Z are longitudinally polarized, and the decay of the τ *via* the charged weak current serves as a natural analyser of the τ polarization. The momentum spectrum of the pion from τ decays, $\tau^- \to \pi^- \nu_\tau$, gets modified due to its polarization and consequently the polarization, P_τ, is measured from the form of the pion energy spectrum :

$$\frac{1}{N_\pi} \cdot \frac{dN}{dX_\pi} = 1 + P_\tau \cdot (2X_\pi - 1), \tag{2}$$

where $X_\pi = \dfrac{E_\pi}{E_{\text{beam}}}$.

The polarization measurement at the Z peak determines (i) the relative sign between the vector ($g_{v\tau}$) and axial-vector ($g_{a\tau}$) coupling of $Z \to \tau^+\tau^-$, and (ii) the electroweak mixing angle :

$$P_\tau \simeq -\frac{2g_{v\tau}/g_{a\tau}}{1+\left(g_{v\tau}/g_{a\tau}\right)^2} \tag{3}$$

$$= -\frac{2\left(1-4\sin^2\theta_{\text{eff}}\right)}{1+\left(1-4\sin^2\theta_{\text{eff}}\right)^2}. \tag{4}$$

(d) Left-right asymmetry :

The left right asymmetry deals with measurement of cross sections with a longitudinal polarization for the e^- beam and it is given by : $A_{LR} = \dfrac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$, where $\sigma_{L,R}$ are the cross sections for $e^-_{L,R} + e^+ \to X$, where X can be any channel. A_{LR} has been measured by the SLD collaboration at SLC. A_{LR} has the advantage of being extremely sensitive to $\sin^2\theta_W$ and insensitive to QED radiative corrections and it depends on the Z coupling to initial state *i.e.*, to e^+e^-.

A_{LR} is related to the experimental measurement by the following relation : $A_{LR} = A_{\exp} / P_e$, where P_e is the measured longitudinal polarization of the e^- beam. The electroweak mixing angle is derived from :

$$A_{LR} = \frac{2\left(1 - 4\sin^2\theta_{\text{eff}}\right)}{1 + \left(1 - 4\sin^2\theta_{\text{eff}}\right)^2}. \tag{5}$$

Another quantity of interest is the foward-backward polarized asymmetry which depends on the Z coupling to the final state and it is given by

$$A_{FB}^{\text{pol}} = \frac{1}{P_e}\cdot\frac{(\sigma_{P,F} - \sigma_{-P,F}) - (\sigma_{P,B} - \sigma_{-P,B})}{(\sigma_{P,F} + \sigma_{-P,F}) + (\sigma_{P,B} + \sigma_{-P,B})}. \tag{6}$$

$$= \frac{3}{4}\cdot\frac{2\left(1 - 4\sin^2\theta_{\text{eff}}\right)}{1 + \left(1 - 4\sin^2\theta_{\text{eff}}\right)^2}. \tag{7}$$

4. Electroweak results from e^+e^- interactions

Data :

Data has been collected over the years 1990 to 1995 as a function of $\sqrt{s}$ around the Z mass. During 1990–1991 the energy range covered was $\left|\sqrt{s} - M_Z\right| < 3\text{GeV}$; in 1992 the data collected at the Z peak; in 1993 at $\left|\sqrt{s} - M_Z\right| < 1.8\text{GeV}$; in 1994 at the Z peak and in 1995 at $\left|\sqrt{s} - M_Z\right| < 1.8\text{GeV}$. The total number of Z events collected by the four LEP experiments during 1990–1995 is $\simeq 16.10^6$ and the break-up is given in Table 2 [2].

Table 2. Number of Z events

Detector	$Z \rightarrow$ hadrons	$Z \rightarrow l^+l^-$
ALEPH	4.2×10^6	0.5×10^6
DELPHI	3.6×10^6	0.4×10^6
L3	3.4×10^6	0.3×10^6
OPAL	3.4×10^6	0.5×10^6

4.1. Mass, width and number of neutrinos :

The precision measurement of the Z lineshape (σ *vs* $\sqrt{s}$) yielded the mass and width of Z which are summarised in Table 3. The number of light neutrinos is determined to be three with a precision of 0.3% [2].

4.2. Determination of electroweak mixing angle :

The asymmetry measurements lead to the determination of the effective electroweak mixing angle, $\sin^2\theta_{\text{eff}}$. Results from different measurements are summarised in Table 4 [2]. It may be mentioned that the LEP average of $\sin^2\theta_{\text{eff}}$ is 0.23192 ± 0.00027 is to be compared with the SLD measurement of 0.23055 ± 0.00041; they differ from each other by 2.8 standard deviation.

Table 3. Mass, width and N_ν

Parameters	Measurements
M_Z GeV	91 186 ± 0 002
Γ_Z GeV	2 495 ± 0 003
Γ_{ll} MeV	83 89 ± 0 11
Γ_{had} MeV	1743 5 ± 2 4
Γ_{inv} MeV	499 8 ± 1 9
$R_l = \Gamma_{had}/\Gamma_l$	20 783 ± 0 029
Number of neutrino species	2 992 ± 0 011

Table 4. Values of $\sin^2\theta_{eff}$

Measurements	$\sin^2\theta_{eff}$
A_{FB} leptons	0 23068 ± 0 00055
A_τ from P_τ	0 23240 ± 0 00085
A_e from P_τ	0 23264 ± 0.00096
A_{FB} b-quark	0 23235 ± 0 00040
A_{FB} c-quark	0 23155 ± 0.00111
$< Q_{FB} >$	0 2322 ± 0 0010
A_{LR} (SLD)	0.23055 ± 0 00041

4.3 *Measurement of R_b :*

R_b is defined as the ratio of the b quark partial width of the Z to its total hadronic partial width : $R_b = \Gamma_{b\bar{b}} / \Gamma_{had}$. An important aspect of this ratio is that most of the Standard Model corrections common to all quarks drop out in this ratio except the b quark vertex correction which depend on mass of the top quark. Measurements available as of end 1995 showed a positive deviation of 3.7 standard deviation from the Standard Model One of the exciting explanations was supersymmetric contribution from light chargino.

During 1996 all the 5 experiments (ALEPH, DELPHI, L3, OPAL, SLD) made a detailed study of the measurement of R_b. Some of the new points are : (i) usage of several different tags for b quark, in particular the inclusion of invariant mass tag, (ii) probability of c quark fragmentation is used from the LEP data itself, (iii) detailed study of various systematics is carried out, (iv) all available data are used and (v) results are obtained by carrying out 13 parameter fit to the LEP and SLD data. This leads to the following value for R_b [2,3],

$$R_b\,(\text{LEP}) = 0.2179 \pm 0.0011, \tag{8}$$

$$R_b\,(\text{SLD}) = 0.2152 \pm 0.0038, \tag{9}$$

$$R_b\,(\text{LEP + SLD}) = 0.2177 \pm 0.0011. \tag{10}$$

The expected value of R_b from the Standard Model is 0.2158 to be compared with the LEP+SLD measurement of 0.2177 ± 0.0011; this leads to a deviation of 1.8 standard deviation.

4.4. Top and Higgs in standard model framework :

The precision achieved in the electroweak measurements at LEP and SLD can be used to check the validity of the Standard Model. The Standard Model basically needs the following 4 quantities : M_Z, M_{top}, M_{Higgs} and α_s. The other quantities which it needs are known. M_Z and α_s are measured at LEP, and thereby fitting all the electroweak data one can determine the values of M_{top} and M_{Higgs}. The accuracy of LEP measurements makes them sensitive to M_{top} and M_{Higgs} *via* weak loop corrections; the dependence on M_{top} is quadratic while the leading M_{Higgs} dependence is logarithmic.

Results of fits are shown in Table 5 [2]. The second column of the table summarises fitted values of M_{top} and M_{Higgs} using LEP data alone. The third column summarises fitted results using all data which include measurements from LEP, SLD, direct measurements of M_W (80.37 ± 0.10 GeV) [4] and M_{top} (175.6 ± 5.5 GeV) at $\bar{\text{p}}\text{p}$ collider [5], and $\sin^2\theta_W$ measurement from νN interactions [6].

Table 5. M_{top} and M_{Higgs}

Parameters	LEP	All data
M_{top} (GeV)	155^{+15}_{-11}	172.7 ± 5.4
M_{Higgs} (GeV)	70^{+147}_{-40}	127^{+127}_{-72}

It is interesting to note that all the existing data show a low mass for Higgs. We show in Figure 3 the observed values of $\Delta\chi^2 \equiv \chi^2 - \chi^2_{\text{min}}$ as a function of M_{Higgs} for the fit with all data. This yields 465 GeV as the one sided 95% confidence level upper limit on the mass of Higgs. It may be mentioned that direct search of Higgs yielded 66 GeV as the lower limit on M_{Higgs}. There are other estimates on the upper limit of M_{Higgs} [7].

5. τ-Physics from e⁺e⁻ interactions

There were problems (a) in the experimental data for τ decay branching ratios, in particular '1-prong deficit' was noted in 1984 and (b) the predicted branching ratios ($B_e \equiv B(e^-\bar{\nu}_e\,\nu_\tau)$ or $B_\mu \equiv B(\mu^-\bar{\nu}_\mu\,\nu_\tau)$) assuming unitarity can be predicted from masses and lifetimes of the muon and tau. Theory and predictions have differed significantly since 1986.

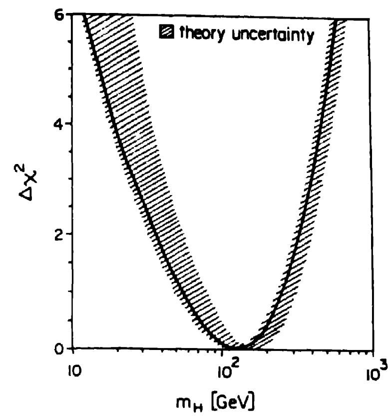

Figure 3. The observed values of $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ as a function of Higgs mass are shown from the fit with all available data.

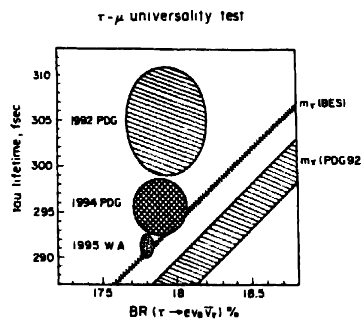

Figure 4. Plot of tau lifetime *vs* branching ratio of tau decay *via* electron mode is shown. The 1995 world average values (1995 W.A) of tau lifetime and branching are in good agreement with the measured tau mass [11].

During the last few years new measurements of branching ratios [8] and lifetimes [9] at LEP [8] and mass of the tau lepton at BES [10], Beijing, have significantly improved the precision. Figure 4 shows the plot of tau lifetime *vs* $B(\tau \rightarrow e^- \bar{\nu}_e \nu_\tau)$; the agreement between the measured values and prediction is clear [11].

6. Some miscellaneous results from e^+e^- interactions

6.1. Upsilon production :

Υ ($\equiv b\bar{b}$) production in Z decays requires emission of energetic gluons and hence the production is highly suppressed. There are two production mechanisms and they are briefly discussed below :

(a) *Colour Singlet Models* : Here the b quark fragmentation is the dominant mode, see Figure 5, leading to $Z \rightarrow \Upsilon b\bar{b}$ with branching fraction as Br = 1.7×10^{-5}.

(b) *Colour Octet Models* : This was introduced to explain high production rate of Υ at the Tevatron [12]. In this model [13] Upsilons are first produced in colour octet, see Figure 5, then they evolve non-perturbatively into colour singlet. The dominant process is the 'gluon fragmentation' : $Z \rightarrow \Upsilon q\bar{q}$ with a branching ratio as Br = 4.1×10^{-5}.

The OPAL collaboration [14], at LEP, from a sample of 3.7 million Z decays identified eight Υ candidates from their decays into e^+e^- and $\mu^+\mu^-$ pairs. The estimated background in the signal region is 1.6 ± 0.3 events. The following branching ratio is obtained for inclusive Υ production :

$$\mathrm{Br}\,(Z \to \Upsilon + X) = (1.0 \pm 0.4 \pm 0.1) \times 10^{-4} \tag{11}$$

It may be mentioned that none of the 8 candidate events is associated with $b\bar{b}$ thereby supporting the colour octet model. The above experimental measurement is to be compared with theoretical expectation of 5.9×10^{-5}.

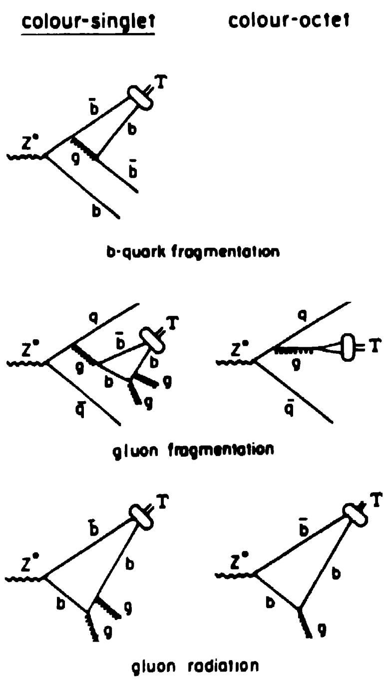

Figure 5. Production mechanisms of upsilons in Z decays from colour singlet and colour octet models

6.2. Measurement of Λ polarization :

In the Standard Model, down-type quarks from Z decays are produced with high longitudinal polarization :

$$P_q = -\frac{2\left(1 - 4\left|Q_f\right|\sin^2\theta_{\mathrm{eff}}\right)}{1 + \left(1 - 4\left|Q_f\right|\sin^2\theta_{\mathrm{eff}}\right)^2} \tag{12}$$

For a strange quark the polarization is $P_s = -0.94$. Hard gluon emission and hadronization processes reduce the polarization P_s. The quark contents of the Λ baryon are strange (s), up (u) and down (d). In the simple quark picture the Λ is supposed to carry the spin of the constituent s quark (light quark pair 'ud' is supposed to be in spin = 0 and isospin = 0 state) and therefore the Λs formed from primary s quark will carry the polarization of s quark.

The ALEPH collaboration [15] measured the longitudinal polarization of Λ to be : $P_\Lambda = -0.32 \pm 0.04 \pm 0.06$ which is to be compared with the expected value of (-0.39 ± 0.08).

6.3. Exclusive decays of Λ_b ($\equiv udb$) :

Exclusive decays of Λ_b have been searched for at hadron colliders and at LEP [16]. The DELPHI collaboration [17] from a sample of about 3 million Z decays have identified four fully reconstructed Λ_b events : three in the $\Lambda_c^+\pi^-$ decay channel and one in the $\Lambda_c^+ a_1^-$ channel. The Λ_b^0 beauty baryon mass is measured to be $5668 \pm 16 \pm 8$ MeV.

7. Summary

The Large Electron Positron collider at CERN is an unique machine running for the last seven years. The first phase of LEP, called LEP1, came to an end during end October 1995. There are four mammoth detectors (ALEPH, DELPHI, L3 and OPAL) which are collecting data. During the LEP1 phase these four detectors together have collected 16 million Z events. Some of the results from LEP1 are : (i) The mass and the width of the Z boson are measured to a precision of : $\frac{\Delta M_Z}{M_Z} = 2.10^{-5}$ and $\frac{\Delta \Gamma_Z}{\Gamma_Z} = 1.10^{-3}$. (ii) The number of light neutrino species is measured to be three with a precision of 0.3%. (iii) The electroweak mixing angle is measured from the asymmetry measurements at LEP and SLD and the values are : 0.23192 ± 0.00027 (LEP) and 0.23055 ± 0.00041 (SLD); they differ from each other by 2.8 standard deviation. (iv) Results presented on the measurement of R_b in 1995 showed a discrepancy of 3.7 standard deviation from the Standard Model. This discrepancy is now reduced to 1.8 standard deviation with new techniques/methods used at LEP and SLD. (v) The precision of electroweak measurements at LEP and SLD, and with the measurements of M_W and M_{top} at the Tevatron collider, the mass of the Higgs is determined to be 127^{+127}_{-72} GeV with the upper limit as 465 GeV at 95% confidence level.

References

[1] ALEPH Collaboration : *Phys. Lett.* **B235** 399 (1990); DELPHI Collaboration : *Phys. Lett.* **B241** 425 (1990); L3 Collaboration : *Phys. Lett.* **B237** 136 (1990); OPAL Collaboration : *Phys. Lett.* **B240** 497 (1990)

[2] LEP Electroweak Working Group, LEPEWWG/97-01, 7 April 1997

[3] ALEPH Collaboration : CERN PPE/97-017, CERN PPE/97-018; OPAL Collaboration CERN PPE/96-167, CERN PPE/97-06; L3 Collaboration : L3 Note 2033, L3 Note 2066; SLD Collaboration : P Rowson, talk presented at Moriond 97

[4] A Gordon *Talk presented at XXXIInd Rencontres de Moriond, Les Arcs*, 16–22 March 1997

[5] CDF Collaboration : J Lys, *Talk presented at ICHEP96, Warsaw*, July 1996, DZERO Collaboration : S Protopopescu, *Talk presented at ICHEP96, Warsaw*, July 1996

[6] CDHS Collaboration : *Phys. Rev. Lett.* **57** 298 (1986), *Z. Phys.* **C45** 361 (1990); CHARM Collaboration : *Phys. Lett.* **B177** 446 (1986); *Z. Phys.* **C36** 611 (1987); CCFR Collaboration : *Proceed XV Workshop on Weak Interactions and Neutrinos* T France and G Bonneaud *et al* eds. *Tufts University and L.A L. Orsay* **Vol II** p 607

[7] A Gurtu *Phys. Lett.* **B385** 415 (1996)

[8] DELPHI Collaboration : *Phys. Lett.* **B357** 715 (1995); ALEPH Collaboration . *Z. Phys.* **C70** 561 (1996), OPAL Collaboration . *Phys. Lett.* **B369** 163 (1996), L3 Collaboration : *Phys. Lett* **B352** 487 (1995); CLEO Collaboration : *Phys Rev.* **D53** 6037 (1996)

[9] DELPHI Collaboration : *Phys Lett* **B365** 448 (1996); OPAL Collaboration . *Phys. Lett* **B373** 341 (1996); ALEPH Collaboration : *Z. Phys.* **C70** 549 (1996); L3 Collaboration : *Phys. Rep.* **236** 1 (1993), CERN-PPE/96-124; SLD Collaboration : *Phys. Rev.* **D52** 4828 (1996)

[10] BES Collaboration . *Phys Rev.* **D53** 20 (1996)

[11] H S Chen *Proceed. XVII Int. Symp on Lepton Photon Interactions*, Beijing, August 1995

[12] CDF Collaboration : FERMILAB-PUB-95/271-E

[13] M Cacciari *et al Phys Rev Lett* **73** 1586 (1994); *Phys Lett* **B356** 553 (1995); P Cho and A Leibovich CALT 68-1988, CALT-68-2020, E Braaten *et al Phys. Rev.* **D48** 4230 (1993), *Phys Rev. Lett* **71** 1673 (1993), V Barger *et al Phys Rev.* **D41** 1541 (1990), K Hagiwara *et al Phys Lett* **B267** 527 (1991); *Phys Lett* **B316** 631 (1993); K J Abraham *Z. Phys.* **C44** 467 (1989); J H Kuhn and H Schneider *Z. Phys* **C11** 263 (1981); W Y Keung *Phys. Rev.* **D23** 2072 (1981)

[14] OPAL Collaboration : CERN-PPE/95-181

[15] ALEPH Collaboration : CERN-PPE/96-04

[16] UA1 Collaboration *Phys. Lett* **B273** 540 (1991), R422 Collaboration . *Nuov Cim* **104A** 1787 (1991), DELPHI Collaboration · *Phys Lett.* **B311** 379 (1993), ALEPH Collaboration *Phys Lett* **B278** 209 (1992), OPAL Collaboration : *Phys. Lett.* **B281** 394 (1992)

[17] DELPHI Collaboration : CERN-PPE/96-16